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ALPINE VEGETATION IN THE VICINITY OF LONG'S PEAK, COLORADO

WILLIAM S. COOPER

(WITH EIGHT FIGURES)

This paper is the result of observations made during the summers of 1904 and 1906. It makes no pretensions to completeness, but is intended to serve as a general survey of an intensely interesting region. It is the intention of the author immediately to begin a more extensive and detailed study.

My thanks are due, first of all, to Dr. E. N. TRANSEAU of the Charleston (Ill.) Normal School, and to Dr. D. S. JOHNSON and Dr. CHARLES K. SWARTZ, of Johns Hopkins University, for many valuable suggestions; also to Dr. AVEN NELSON, of the University of Wyoming, for determination of plants.

I. Location and general topography

The Front Range of the Rocky Mountains, which in the vicinity of Long's Peak constitutes the continental divide, is a rugged mass carved from the Archean granite and gneiss. South of Long's Peak, which is an eastern projecting spur therefrom, its direction is nearly north and south, and it stands about 24^{km} west of the eastern border of the mountain region. North of Long's Peak it turns to the northwest, and continues in this direction for a distance of 24^{km}, until it meets the Medicine Bow and Rabbit Ear Ranges; the continental divide is continued in the latter range. At the eastern base of the Front Range, just north of Long's Peak, lies Estes Park, a mountain valley which here separates the main range from the lower forest-clad mountains toward the east. Estes Park lies at an altitude of 2285^{m}; the average altitude of the divide is 3810^{m}; most of the peaks exceed 3900^{m}, and Long's Peak attains an altitude of 4350^{m}.

The localities studied are on the summit and eastern flank of the Front Range, from Mt. Tyndall, 6.4^{km} south of Long's Peak, to Stone's Peak, 16^{km} northwest. Particular attention was given to two glacial cañons: the Chasm Lake cañon, immediately below the east face of Long's Peak; and Glacier Gorge, west of the same mountain.

II. Physiography

A. PRESENT.—For convenience we may divide the physiographic features of the region into two groups: (1) the flat summit of the divide and slopes similar to it; (2) the glacial cañons.

The summit of the divide is an elevated plateau, in some portions level. more often gently rolling (*figs. 1, 2*). In places it is 1.6^{km} or more wide, in others it narrows to less than 0.4^{km}. A few low peaks rise from it, often near its edge, so that they have a precipitous face on that side. The surface is covered with a rather thin layer of rock fragments split off by frost and temperature changes, of small size in most places, but much larger on the higher summits. Similar in every way to the summit of the divide are the slopes that descend to the region of timberline where glacial erosion has not formed cliffs.

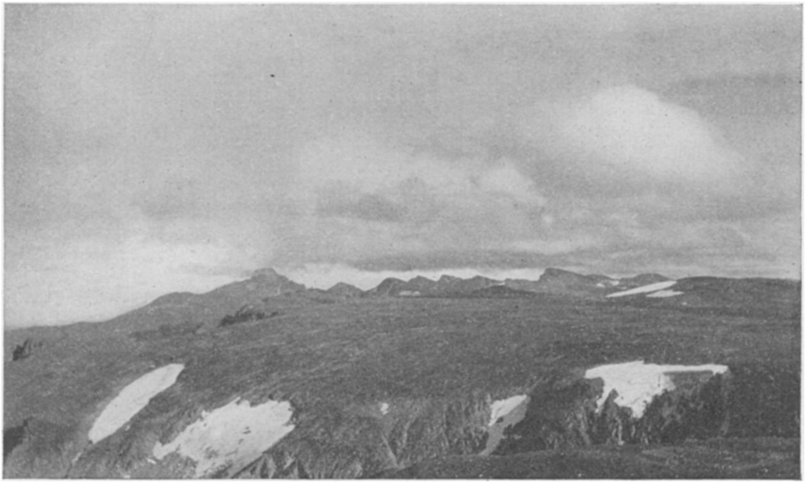

FIG. 1.—Summit of the continental divide from Stone's Peak; Long's Peak at the left; the dry meadow covering the flat surface of the divide is shown.

The glacial cañons head in a series of fine cirques, immediately under the steep cliffs that form the face of the continental divide (*fig. 3*). They are separated from each other by projecting spurs of varying width, sometimes flat-topped, but oftener mere ridges, so close together were the sources of the glaciers. When flat-topped they are essentially similar to the summit of the divide, and are in fact continuous with it, being covered with a thin layer of frost-broken fragments. Some of the ridges bear high rugged peaks, but in most cases they decrease gradually in altitude away from the divide, and frequently end in long interlobate or medial moraines, where the adjacent glacier tongues met or coalesced. The floors of the cañons descend toward the lower altitudes in an alternating series of very gentle slopes and abrupt steps, the latter often 30^{m} or more in height.

B. HISTORICAL.—A glance at the physiographic history of the region will make clearer the present conditions and processes. For the purpose of this paper, it is unnecessary to go back farther than the time of Pleistocene glaciation, since during that period practically every trace of vegetation must have been destroyed. The Front Range in the region studied was glaciated during the Pleistocene period over a width of about 25^{km}[1]. The summit of the range was deeply covered with snow, which, accumulating in larger quantities in favorable locations along the flanks of the range, became consolidated at these points into glacier ice and commenced the work of shaping and modifying the cañons.

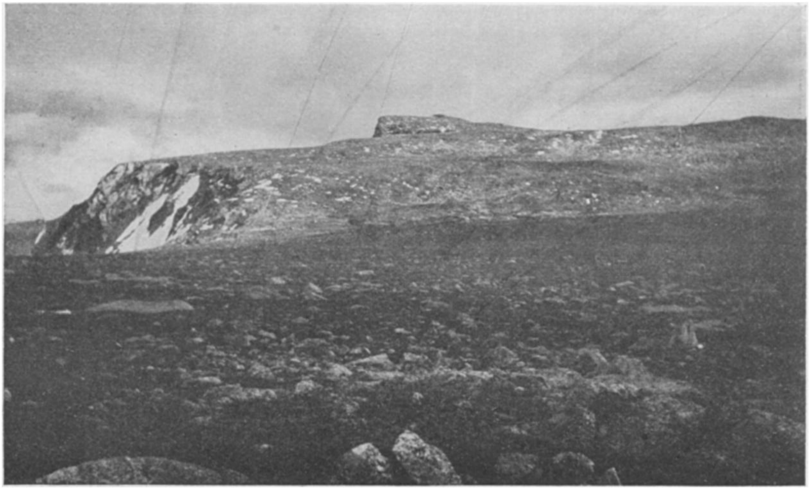

FIG. 2.—Summit of the divide near Mt. Tyndall; a more detailed view of the dry meadow, showing also the top of cliffs that surround a glacial cirque.

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[1] KING, CLARENCE, Exploration of the Fortieth Parallel.

In due time the climate began to change and the amount of snow to decrease accordingly. Finally, the winter snowfall decreased to such an extent that the summit of the divide and the gentler slopes became bare during the summers. These surfaces had heretofore been protected by their load of snow from the process of weathering. Now, however, began the work of frost and of temperature changes, which is responsible for the condition of the summit today. The thinness of the covering of rock fragments on these surfaces is due to the protection from sudden changes of temperature afforded the solid rock beneath by the broken rock itself, with the layer of vegetation that has become established upon it.

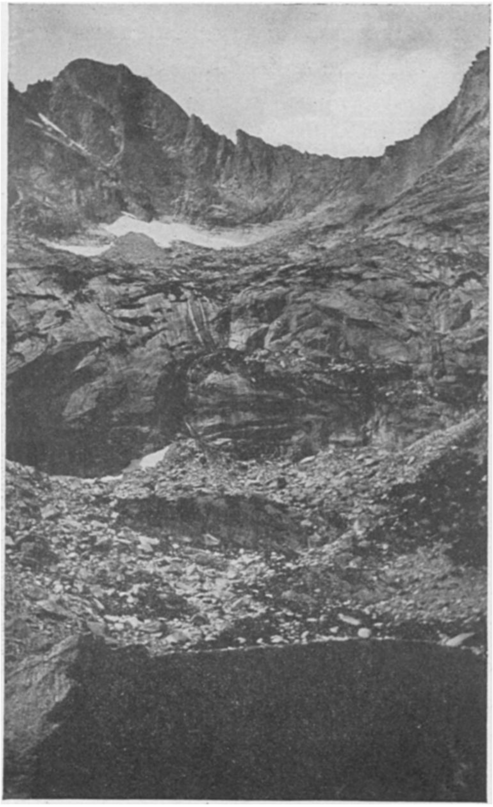

FIG. 3.—View in Glacier Gorge, showing glacial topography and wet meadow areas on ledges; a glacial lake in the foreground, and snow banks below the cliffs.

In the meantime the glaciers themselves steadily shrank, because of the decreasing supply of snow at their sources. The large accumulation of névé in the cirques, however, enabled them to hold out long after the perennial snow mantle of the summit and exposed slopes had disappeared. In fact, there still remain at the heads of several of the cañons remnants of the former ice tongues, which, though small, are true glaciers.

The cañons thus formed exhibit the usual glacial characteristics (*figs. 3–6*). At their lower ends are found series of terminal moraines and for some distance up there are extensive lateral moraines. The floors of the cañons, except for an occasional small terminal moraine, are nearly bare of morainic material, such as is present being an exceedingly sparse scattering of single bowlders. The floors are very smooth, frequently almost polished, and are marked by the usual scratches and striae. *Roches moutonnées* are numerous but not prominent. At intervals are found the great "steps" mentioned above, where were the ice falls of the glaciers. At their bases are nearly always lakelets, occupying basins excavated by the ice, which naturally possessed increased erosional power at these points. Lake basins are not, however, exclusively confined to the bases of the "steps."

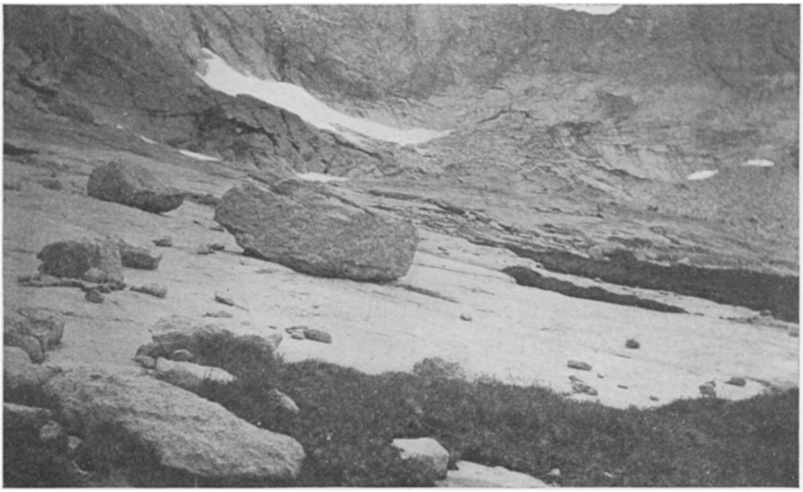

FIG. 4.—Smooth glaciated floor of Glacier Gorge, with scattered glacial detritus; the wet meadow patches have formed among this material.

The results of post-glacial weathering in the cañons are seen in the masses of talus piled along the bases of the cliffs. Where the cañons are narrow, the weathered material covers the whole breadth of the floor, and has begun to fill many of the lake basins with large fragments. Usually, however, there is a wide central space which the talus from the side cliffs does not reach. Another effect of weathering, more important ecologically than physiographically, is the enlarging of the cracks or joint planes in the smooth floor of the cañons, by disintegration of their edges and the deposit, in or near the cracks, of the fine disintegrated material. Stream erosion has so far produced practically no effect upon the topography of the upper portions of the cañons.

III. Vegetation

In considering the vegetation of the higher mountain region, we naturally divide it into two great formations: the alpine grassland, and the forest, and place the division between these at timberline. In general this arrangement is a right one for the region, but in studying the vegetation dynamically we are compelled to recognize an exception in the wet meadows of the cañons. Above timberline we find two types of grassland: the dry meadow, occupying the exposed slopes and ridges; and the wet meadow, in the upper portions of the glacial cañons. The former is a true climatic grassland. The latter, however, as will be shown, is probably not permanent grassland brought about by climatic factors, but is a stage in the forest succession, and, conditions remaining the same, will become forest after the lapse of sufficient time. In this paper the term "alpine grassland" will be used to include both dry and wet meadow. We will consider first the development of these two types of alpine meadow; and second, the forest formation in its successional relation to them.

A. THE ALPINE GRASSLAND

1. *The dry meadow*

The societies which form the stages in this succession (*figs. 1, 2*) cover a large part of the area above timberline—an area which is practically coextensive with the flat summit of the range and the slopes similar to it, which, as has been said, are covered with a layer of broken fragments. While this layer of broken material protects the bed rock from further weathering, the fragments themselves are continually disintegrating under the influence of frost and of lichens. Disintegration by lichens is an important process here as is evidenced by the thick crust of these plants upon every stone.

Every stage in the development of the dry meadow may be seen on the summit of the range. On the more elevated portions, where have been split off blocks of very large size, no plants except lichens have as yet been able to gain a foothold. Where the blocks are smaller and more disintegrated, a layer of fine material has accumulated around and among them—the first step in the formation of a soil; and here a few herbaceous plants of extreme xerophytic nature, such as *Silene acaulis*, *Phlox caespitosa*, *Dryas octopetala*, have established themselves. A further stage is seen where the vegetation has become more luxuriant both in number of species and of individuals, frequently partially concealing the remnants of the disintegrating rock fragments. In the mature dry meadow the rock fragments have mostly broken down to form, with the humus deposit, an even layer of soil which is well covered by a growth of low herbaceous vegetation. The dry meadow of this region resembles quite closely the so-called "alpine tundra" of the summit of Mt. Ktaadn, Maine, as described by HARVEY,[2] and observed by the author of this paper. It differs from that in the practical absence of mosses and fruticose lichens so characteristic of the summit of Ktaadn. At the same time, it does not perfectly correspond with the common idea of meadow land, since the vegetation is low and of a decidedly xerophytic nature. As is the case in the Pike's Peak region[3] the mature dry meadow has two seasonal stages, the earlier characterized by the prominence of *Rydbergia grandiflora* in flower, the later by *Campanula rotundifolia.* It must not be supposed that the soil on these exposed summits and slopes, thin as it is, is everywhere dry. Even along the summit of the divide are frequent depressions receiving all the run-off from the surrounding slopes, which often are gentle and embrace large areas. The solid granite beneath prevents absorption; therefore the water remains stagnant or flows very slowly over the surface. The supply seems to be fully equal to the loss by evaporation, for these areas remain wet all summer long. The depressions are characterized by a more luxuriant vegetation, and therefore deeper deposits of humus, but the species are the same as those found on the drier portions of the meadow. A list of the dominant species of the dry meadow follows:

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[2] HARVEY, LEROY H., A study of the physiographic ecology of Mt. Ktaadn, Maine. University of Maine studies, No. 5.

[3] CLEMENTS, F. E., Research methods in ecology.

PRINCIPAL SPECIES.—Silene acaulis L., Sieversia turbinata (Rydb.) Greene, Dryas octopetala L., Phlox caespitosa Nutt., Campanula rotundifolia L., Rydbergia grandiflora (T. & G.) Greene.

SECONDARY SPECIES.—Selaginella densa Rydb., Deschampsia caespitosa alpina Vasey, Trisetum subspicatum (L.) Beauv., Carex atrata L., Juncoides spicatum (L.) Kuntze, Zygadenus coloradensis Rydb., Lloydia serotina Reichenb., Polygonum viviparum L., Oreobroma Grayi (Britton) Rydb., O. pygmaea (Wats.) Howell, Arenaria sajanensis Willd., Draba crassifolia Graham, Sibbaldia procumbens L., Dasiphora fruticosa (L.) Rydb., Trifolium dasyphyllum T. & G., Oreoxis alpina (Gray) C. & R., Primula angustifolia Torr., Androsace subumbellata (A. Nels.) Small, Douglasia Johnstonii A. Nels., Polemonium confertum Gray, Mertensia viridis Nels., Castilleja puberula Rydb., Pedicularis Parryi Gray, Solidago scopulorum (Gray) A. Nels., Tetraneuris acaulis (Nutt.) Greene, Tonestus pygmaeus (T. & G.) Nels., Erigeron pinnatisectus (Gray) Nels., Artemisia scopulorum Gray.

2. *The wet meadow*

It must be borne in mind that on account of a smaller deposit of snow, due to exposure to the wind and sun, the summit of the range and the unglaciated slopes were first exposed, while the cañons still contained glaciers fed from the névé accumulated in the cirques at their upper ends. Thus it was long after the dry meadows above had begun their development when vegetation, following the retreat of the ice, first gained access to the upper portions of the cañons. At the present day the spruce-fir forest extends up the cañons to an altitude of about 3350^{m}. Above this is an area supporting a mesophytic meadow vegetation, which, however, only partially covers the ground, being confined to the vicinity of the watercourses. Still higher, where the last remnants of the ice lingered, there is no vegetation save a sparse growth of lichens. In the heads of the cañons, therefore, we may study primary invasion in all its stages, and the next few paragraphs will be devoted to a description of it as observed in these places.

A. THE GLACIAL CAÑON AS A HABITAT.—*Atmospheric conditions.*—As to the atmospheric conditions in the cañons I can give no exact data, but it may be said with certainty that they are comparatively favorable to plant growth—much more so than in the region of the dry meadows. The most noticeable difference between the two habitats, in regard to atmospheric conditions, is the exposure to the full force of the wind on the dry meadows, contrasted with the effective shelter from that agent afforded by the cañon walls. The difference in altitude between the two habitats, averaging about 610^{m}, also favors the cañons, since atmospheric rarity tends to increase evaporation.

Ground water.—The smooth polished floor of the cañons has already been described. In some parts the surface slopes gently and evenly; in others there are low rounded prominences (*roches moutonnées*) with depressions between. The greater part of this region is dry during all of the growing season, since the surface drainage from the snow banks above is the only source of moisture that need be taken into account. The small amount of rainfall during the growing season may be neglected altogether, since the smooth rock surfaces cannot retain it, and it very soon evaporates or joins the drainage channels from the snows. Snow accumulates at the bases of the upper cliffs in large quantities, and many of the drifts remain through the summer, affording by their melting a constant supply of water to a restricted portion of the area below. The drainage channels from the various permanent drifts form a network over the cañon floor in following the principal depressions among the *roches moutonnées*. Some cases were observed where the water flowed in a broad sheet for long distances over a smooth gently sloping rock surface.

Sources of soil materials.—The soil materials which render possible the establishment of the pioneers of the higher plants are derived principally from two sources: rock decay and wind-blown dust. Rock decay has made very little progress in the cañon heads since glacial times. Since the process is conditioned by the presence of moisture, the larger part of that which has been done and is now being done is within the sphere of influence of the drainage channels. As has been said in describing the physiography of the region, decomposition is going on principally along joint planes, and the fine products of this process are either deposited in the cracks near to where they were produced or are carried down by flowing water and deposited in other situations.

I believe that wind-blown dust is an important addition to the scanty supply of soil material available to the pioneers. Its source doubtless is largely the dry meadows above the cañons, where during the summer large areas of sparsely covered soil become desiccated. Some of the dust from this and other sources is doubtless carried directly to its final destination on the cañon floors. It is likely, however, that a greater amount is brought down by the streams from the snow banks at the base of the upper cliffs, upon which it had fallen, perhaps years before. The wet surface of the drifts would hold all such fine material deposited upon it. This deposit is not so slight as might be imagined, for during a single summer the drifts become so coated with dust that the discoloration is conspicuous at a great distance. The fate of the dust thus deposited is as follows: Most of the run-off from a large snow bank in an arid mountain region comes from the melting of the compact basal portion. The water which results from surface melting nearly all evaporates. Thus the layer of dirty snow upon the surface of the drift is slowly but continually sinking. Each winter a fresh layer of snow is deposited, which, during the following summer, accumulates a layer of dust upon its surface. Frequently a section through a snow bank will reveal a series of these dirt bands, roughly marking off what remains of each winter's snowfall. It is evident that because of the basal melting, these dirt bands will finally sink to the bottom of the drift, and that the matter which the dirty layers contain will be carried down with the stream of water which issues from beneath the snow bank, often with great velocity. This material, converging from numerous sources to a few restricted drainage areas, is by no means to be neglected, and being chiefly organic in nature, it is a valuable contribution to the making of the first soil. Being exceedingly fine material, it may be carried to a considerable distance, and is deposited in basins, or wherever the velocity of the stream slackens. The disintegrated rock material, on the other hand, being comparatively coarse, if carried away at all, is deposited very near to its point of origin.

As soil producers, lichens have accomplished practically nothing in the glacial cañons. The fact that the rock is a hard granite, and the smoothness of its surface, as well as the comparatively short time that the rock has been exposed, are sufficient to explain this.

B. THE INVASION OF THE CAÑONS.—The unimportance of lichens in preparing for the establishment of the higher plants has just been mentioned. The advance of the latter must therefore be conditioned by the other sources of soil material, rather than by any furnished by lichens. And so we find two groups of invaders, one making use principally of the decomposed rock material in the cracks, the other developing later, but usually on new ground, in basins and very wet places, and profiting from the organic material brought down from the snowdrifts.

In cracks and joints of the floor we find a pioneer group consisting of the following species, all but one or two of which are perennials.

1.—Deschampsia alpicola Rydb., Agrostis tenuiculmis Nash, Trisetum subspicatum (L.) Beauv., Carex atrata L., Juncoides spicatum (L.) Kuntze, Sagina Linnaei Presl., Draba crassifolia Graham, Sibbaldia procumbens L., Androsace subumbellata (A. Nels.) Small, Artemisia scopulorum Gray.

2.—Salix petrophila Rydb., Oxyria digyna (L.) Camptd., Saxifraga debilis Engelm., Senecio Fremontii T. & G.

The species in the first group, to which further exploration would doubtless add many more, are commonly found in the dry meadows. Since these meadows are all above the level of the cañon floors, this group of pioneers must have come from seeds blown or washed down from them. There is one other possibility—that these plants have followed the glaciers as they retreated. It seems likely, however, that pioneers in the invasion of the lower portions of the cañons were plants belonging to lower altitudes and more favorable conditions; since they were as well sheltered from the wind as are the pioneers of today, and the water supply was far more abundant. The plants in the second group are commonly found in clefts and among bare talus in the higher altitudes. These species, with those of the first list, constitute a group of invaders of xerophytic character from higher altitudes. They do not occupy a definite zone, but are scattered over a broad area of the cañon floor wherever conditions permit them to exist. In some measure they prepare the way for the group of invaders that comes from the opposite direction, but like the lichens they are relatively unimportant, and, as will be shown, the plants that come in from below to fill the depressions may be entirely independent of any aid from earlier arrivals. Sometimes, however, the cracks containing these plants may become the starting-point for quite large mats of turf. If the water supply is abundant enough to make possible the establishment in a crack of the more mesophytic sedges and grasses, such as grow in the basins soon to be described, these may spread out over the surface of the rock by means of rootstocks, forming a thick and permanent carpet which may be lifted from the rock at its edges, but which is firmly anchored at its point of origin.

We now come to the group of invaders that is advancing toward the heads of the cañons from below. The pioneers are few in species, but exceedingly numerous in individuals, covering the areas over which they advance with a thick carpet of vegetation. Their line of attack is along the watercourses. It has been said that deposition of earthy matter from the melting snows, fine rock material, and some organic matter from the plants growing in cracks farther up, is continually going on where the current of the watercourses slackens. The first plants to appear in this sediment are usually mosses, including *Philonotis fontana*, which sometimes becomes established even in shallow water. The mosses are followed by species of Carex, which by means of their creeping stems spread extensively and form thick mats. Grasses now come in, with a scattering of other herbs characteristic of marshy ground and stream banks, nearly all of which are found in marshy situations at considerably lower altitudes. The deposits of humus from these plants hastens the filling-in of the depressions, and the result is a wet swampy meadow with one or

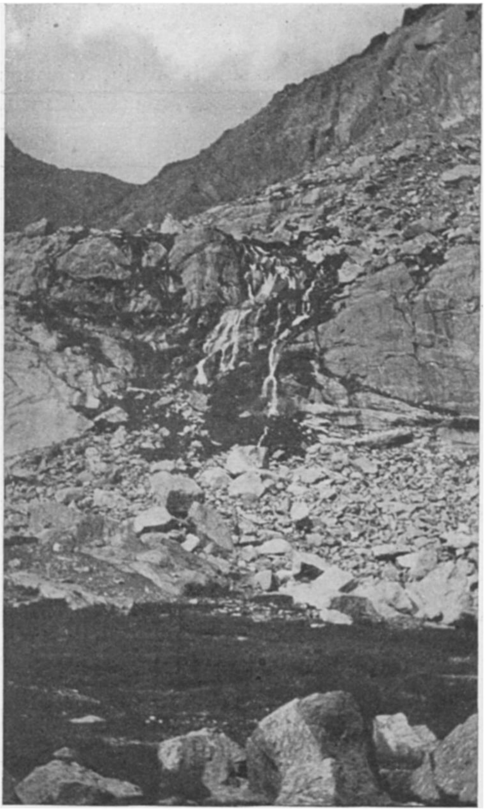


FIG. 5.—View in Chasm Lake Cañon; the wet meadow vegetation in the foreground has completely filled a basin; similar patches of vegetation are visible in the vicinity of the cascades.

more streams meandering through it (*fig. 5*). These streams often run over the rock itself, since the current has so far kept their beds free from sediment. Prominent plants growing in these wet meadows are as follows:

Lycopodium selago L., L. annotinum L., Carex (several species) dominant, Caltha rotundifolia (Huth) Greene, Sedum rhodanthum A. Gray, Sieversia turbinata (Rydb.) Greene, Kalmia microphylla (Hook.) Heller, Primula Parryi A. Gray, Gentiana frigida Haenke, G. plebeja Holmii Wettst., Swertia congesta A. Nels., Elephantella groenlandica (Retz.) Rydb., Crepis alpicola (Rydb.) A. Nels.

Later a few shrubs make their appearance. *Betula glandulosa* is by far the commonest of these, and *Dasiphora fruticosa* and *Salix chlorophylla* are frequent.

Where a stream flows among glacial débris scattered over a smooth gently sloping rock surface, plants themselves are instrumental in forming small basins. Fine material accumulates around the rock fragments, and in this mosses obtain a foothold. From the rock fragments as centers mats of moss spread out, and these coalescing partially dam up the stream, so that more fine material is deposited. The development of the meadow then progresses as in the natural rock basins. Frequently the damming-up of its course deflects a portion or all of the stream, and in its new course it encounters other débris where the process is repeated. These little meadow patches often coalesce to form areas of quite respectable size. The turf mats that start from the cracks also sometimes become joined to these, and thus in various ways considerable areas on the cañon floors obtain a solid covering of herbaceous vegetation (*figs. 4, 6*). Ledges on the cañon walls, where water trickles over them, are covered with a turf mat similar in composition to that upon the cañon floor (*fig. 3*). Where cascades occur, principally at the great "steps," there is naturally an abundant vegetation, consisting of mosses, sedges, and other herbs growing within the influence of the spray (*fig. 5*). The lake basins are so large and deep that comparatively little filling has been accomplished. The shallower portions along the shore are partially converted to meadow, and where a lake occurs at the base of a "step" good-sized alluvial cones extend out into the water at the upper ends. Of course this is not the case with the highest lakes, where very little alluvial matter is available.

The mature wet meadow is thus of a decidedly mesophytic character. Composed as it is of a thick bright-green turf of sedges, grasses, and other flowering plants, it has a truly meadow-like appearance.

It must be borne in mind that only the depressions have been thoroughly taken possession of by vegetation (*fig. 6*). The higher and drier portions of the cañon floor—the *roches moutonnées*—including much more than half of the total area, are still bare, save for a sparse covering of lichens, and a few xerophytic herbs in the crevices. These areas, of course gradually decreasing, but with exceeding slowness, are destined to remain very much the same for a long time. Far down the cañons, in the midst of the forest, there are many places where the bare floor is still exposed, more incrusted with lichens and slightly more decomposed, but nevertheless surprisingly similar to the bare areas at the cañon heads.

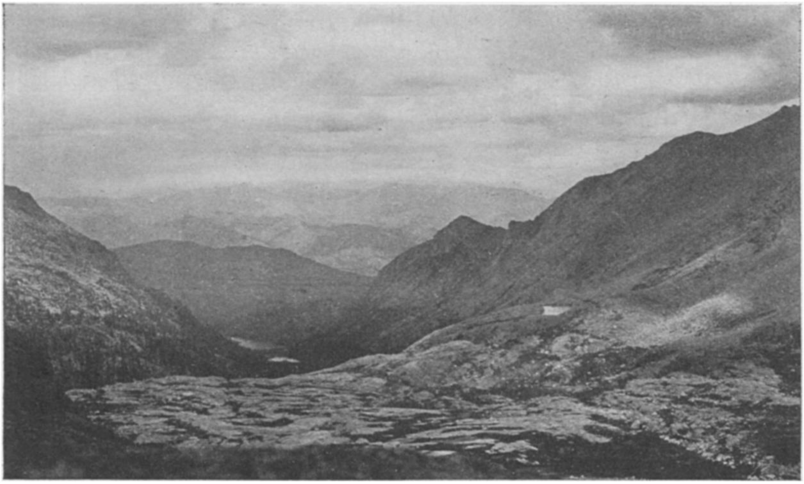


FIG. 6.—View looking down Glacier Gorge; the dark areas in the foreground are wet meadow occupying depressions in the cañon floor; scattered over the meadow areas are still darker patches, the Picea *Krummholz;* farther down the cañon may be seen the Picea-Abies forest surrounding two glacial lakes.

B. THE FOREST

For the present purpose we need to consider only the upper forest zone, which in this region is composed of two societies governed by the factor of soil water content. The white pine society consists of an almost pure growth of *Pinus flexilis.* It covers the dry summits and upper slopes of the ridges between the cañons up to the limit of tree growth. The spruce-fir society is confined to situations where there is an abundant soil water content. It follows the cañon bottoms up to where they emerge above timberline, and extends up the sides as far as there is a sufficient amount of ground water available. The two trees that dominate the society are the Engelmann spruce (*Picea Engelmanni*) and the subalpine fir (*Abies lasiocarpa*). The latter is more abundant close to the streams, and seldom or never in this region ascends quite to timberline.

1. *The Krummholz* (*figs. 7, 8*)

The altitude of the present upper limit of tree growth averages about 3350^{m}, with a range between extremes of perhaps 150 or 180^{m}. Since *Abies lasiocarpa* does not ascend to timberline, the *Krummholz* is composed of two trees only, *Pinus flexilis* and *Picea Engelmanni*, the former on the ridges, the latter in the cañons. Both reach their upper limit at approximately the same altitude, but their appearance and behavior there is so strikingly different that a description of each will be of interest.

PINUS FLEXILIS.—This tree, even when growing in its most congenial habitat, is very irregular and contorted. In its *Krummholz* form it assumes the most fantastic shapes and yet in all of these a general uniformity of behavior may be seen. A very typical growth of the *Krummholz* form is found at timberline on the Long's Peak trail (*figs. 7, 8*). Here there is considerable exposure to the prevalent west wind which sweeps with great force over a saddle on the ridge behind. The trees form an open growth, with the individuals usually growing singly. They are of great age, and often 30^{cm} thick, but few are more than 1.5^{m} in height. The live branches all point to the eastward, those on the windward sides are dry and dead, and the windward portions of the trunks are in nearly every case devoid of bark. Frequently the greater part of the trunk is worn away by the ice particles borne by the winter gales. The degree of exposure to the winds from the west determines the height of the tree. If somewhat sheltered, the trunk may be nearly erect, but in the most exposed places it becomes absolutely prostrate (*fig. 8*), creeping along the ground for 4.5 to 6^m, and sometimes partially or wholly buried in sand and needles. It is a noticeable fact that on the ridges the *Krummholz* ends abruptly—in other words there is a very definite timberline. Beyond the main mass of the forest outlying groups of trees are rare, and are never at any distance from it.

PICEA ENGELMANNI.—In the cañons, on the contrary, it is seldom possible to determine the precise limit of the forest formation. In ascending we find that the trees become more scattered and at the same time smaller, until finally they are mere bushes, growing singly or in groups scattered over the wet meadow areas. They are seldom much contorted, nor do they often show the effects of wind and ice crystals. Unlike the white pine, the Engelmann spruce persists in its upright habit. In its most common *Krummholz* form, as found in most parts of the cañon floors, it has a thick erect trunk a meter or two in height, and a broad flat matted crown composed of branches so tough and intricately woven that where the trees grow close together it is often possible to walk for considerable distances over their tops. Where *Picea Engelmanni* occupies more exposed positions it almost always

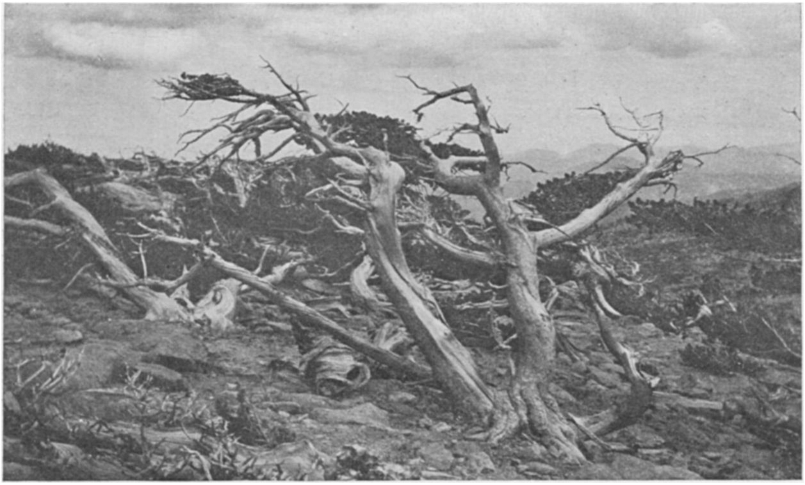


FIG. 7.—*Krummholz* form of *Pinus flexilis* near the Long's Peak trail; the view is from the windward side.

retains its erect habit, but the branches point to leeward of the prevalent wind. Occasionally the trunk is prostrate, but in these cases erect branches are produced, the branchlets of which are turned to leeward. There is frequently a tendency in this species, when growing, as it occasionally does, in much exposed places, to form long narrow groups of individuals, parallel to the direction of the prevailing wind, the height gradually rising from two or three decimeters at the windward end to a meter or more at the leeward end of the group. The explanation of this phenomenon evidently is that some small shelter allows a seedling to live and develop into a small tree; and this gives protection in its lee to others, each of which in turn is able to rise slightly higher than the one in front. The same mode of growth is seen also in such small shrubs as *Betula glandulosa* and the low alpine form of *Populus tremuloides*, which are found in the same habitat with *Picea Engelmanni*.

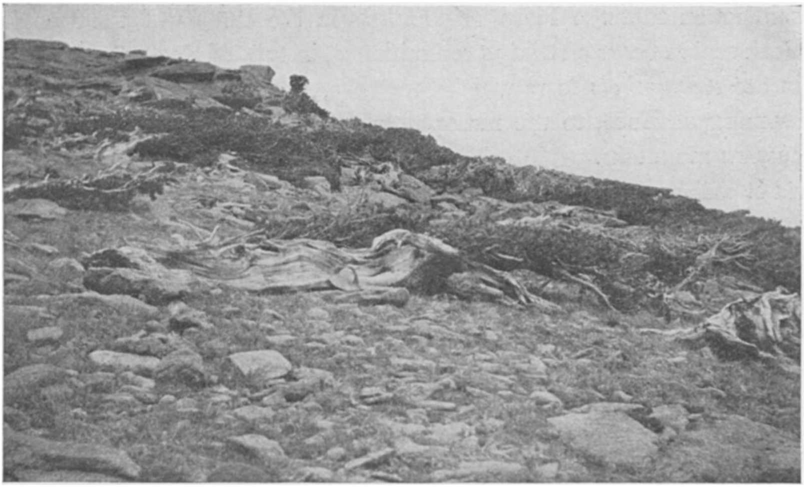
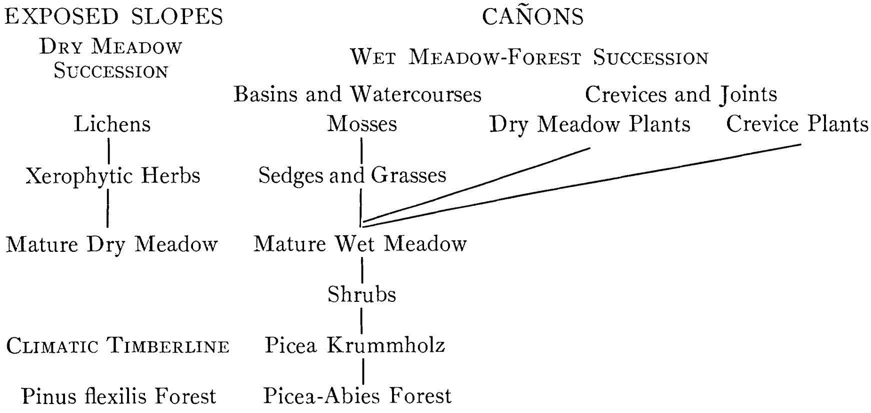


FIG. 8.—*Pinus flexilis* growing in a very exposed situation near the Long's Peak trail.

Having now a general view of the forest at its upper limit, we will consider the question as to whether these two trees are at present invading the grassland. The evidence here, though it is not as complete as might be wished, points toward the general conclusion that the forest formation is advancing in the cañons, but that on the ridges it has reached its climatic limit. The aged, battered, and twisted white pines, with no young trees among them, indicate a repulse in the effort of the forest to ascend the ridges; while, on the other hand, the gradual decrease in height, the scattering of individuals and groups in advance of the main mass, suggest that in the cañons the forest is still advancing—that it has not yet reached the point where tree growth is climatically excluded. HARVEY[4] has cited a similar condition in evidence that the forest is not climatically excluded from the summit of Mt. Ktaadn. It is an interesting fact in this connection that the Picea *Krummholz* in the cañons of the Long's Peak region bears a striking resemblance, in type of trees represented, in the *Krummholz* form which they take, and in the manner of their seeming advance, to the mesophytic Picea-Abies *Krummholz* of the eastern mountain.

It will be well at this point to recall the fact that the agency most important in preventing tree growth is dry wind during frosty weather, since it accelerates transpiration to a high degree, while the frozen condition of the ground prevents a renewal of the water supply.[5] The conditions in the Long's Peak region—the permanent timberline on the exposed ridges and the advancing forest in the sheltered cañons—agree perfectly with this theory.



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[4] HARVEY, LEROY H., *Op. cit.*

[5] KIHLMAN; referred to by SCHIMPER, Plant geography 78.

C. THE SUCCESSIONS

In this study we have endeavored to trace in a general way the stages through which the vegetation of the alpine region has passed. It remains only to bring into an orderly arrangement the successions and their stages which have been described. This may best be done by means of the foregoing diagram, which in the light of what has gone before will need no further explanation.

IV. Summary

In the retreat of the Pleistocene snow masses the unglaciated slopes and summit of the divide were first uncovered and occupied by vegetation. On these areas the xerophytic "dry meadows" of today have developed.

Owing to the slower shrinkage of the valley glaciers, invasion of new areas is still going on at the heads of the glacial cañons.

The glacial cañon as a habitat is characterized by (1) comparatively favorable atmospheric conditions, (2) restriction of surface water to limited areas, (3) dependence of the production and distribution of soil materials upon surface water.

These conditions result in a vegetation consisting of a lichen society inhabiting the dry rock surfaces for an indefinite length of time, and a wet meadow society confined to the vicinity of the drainage channels. The latter society is preceded by two groups of pioneers: one, the less important, derived from the xerophytic dry meadows, becoming established in cracks and joints of the floor; the second, mesophytic in character, invading from the lower altitudes, occupying depressions and very wet places.

The evidence at hand indicates that the forest, represented at timberline by *Pinus flexilis* on the ridges, and by *Picea Engelmanni* in the cañons, has reached its climatic limit on the ridges, being prevented from further advance by the dry winter winds; but that in the cañons the forest is still invading the wet meadow society.

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